ESTIMATED PROBABILITY OF A CERVICAL SPINE INJURY DURING AN ISS MISSION

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Introduction: The Integrated Medical Model (IMM) utilizes historical data, cohort data, and external simulations as input factors to provide estimates of crew health, resource utilization and mission outcomes. The Cervical Spine Injury Module (CSIM) is an external simulation designed to provide the IMM with parameter estimates for 1) a probability distribution function (PDF) of the incidence rate, 2) the mean incidence rate, and 3) the standard deviation associated with the mean resulting from injury/trauma of the neck.

Methods: An injury mechanism based on an idealized low-velocity blunt impact to the superior posterior thorax of an ISS crewmember was used as the simulated mission environment. As a result of this impact, the cervical spine is inertially loaded from the mass of the head producing an extension-flexion motion deforming the soft tissues of the neck. A multibody biomechanical model was developed to estimate the kinematic and dynamic response of the head-neck system from a prescribed acceleration profile. Logistic regression was performed on a dataset containing AIS1 soft tissue neck injuries from rear-end automobile collisions with published Neck Injury Criterion values producing an injury transfer function (ITF). An injury event scenario (IES) was constructed such that crew 1 is moving through a primary or standard translation path transferring large volume equipment impacting stationary crew 2. The incidence rate for this IES was estimated from in-flight data and used to calculate the probability of occurrence. The uncertainty in the model input factors were estimated from representative datasets and expressed in terms of probability distributions. A Monte Carlo Method utilizing simple random sampling was employed to propagate both aleatory and epistemic uncertain factors. Scatterplots and partial correlation coefficients (PCC) were generated to determine input factor sensitivity. CSIM was developed in the SimMechanics/Simulink environment with a Monte Carlo wrapper (MATLAB) used to integrate the components of the module.

Results: The probability of generating an AIS1 soft tissue neck injury from the extension/flexion motion induced by a low-velocity blunt impact to the superior posterior thorax was fitted with a lognormal PDF with mean 0.26409, standard deviation 0.11353, standard error of mean 0.00114, and 95% confidence interval [0.26186, 0.26631]. Combining the probability of an AIS1 injury with the probability of IES occurrence was fitted with a Johnson SI PDF with mean 0.02772, standard deviation 0.02012, standard error of mean 0.00020, and 95% confidence interval [0.02733, 0.02812]. The input factor sensitivity analysis in descending order was IES incidence rate, ITF regression coefficient 1, impactor initial velocity, ITF regression coefficient 2, and all others (equipment mass, crew 1 body mass, crew 2 body mass) insignificant.

Verification and Validation (V&V): The IMM V&V, based upon NASA STD 7009, was implemented which included an assessment of the data sets used to build CSIM. The documentation maintained includes source code comments and a technical report. The software code and documentation is under Subversion configuration management. Kinematic validation was performed by comparing the biomechanical model output to established corridors.

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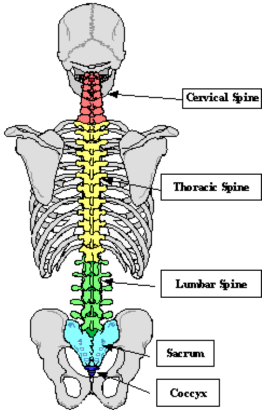
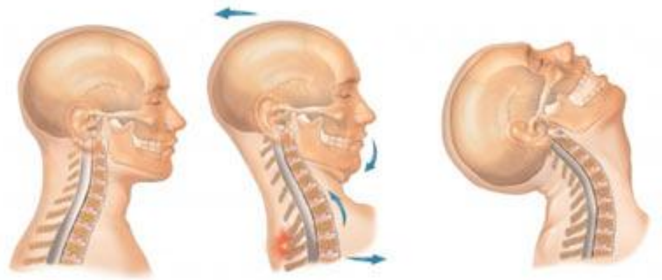
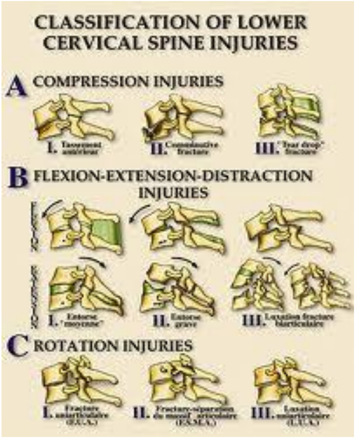
Cervical Spine Injury Model - CSIM

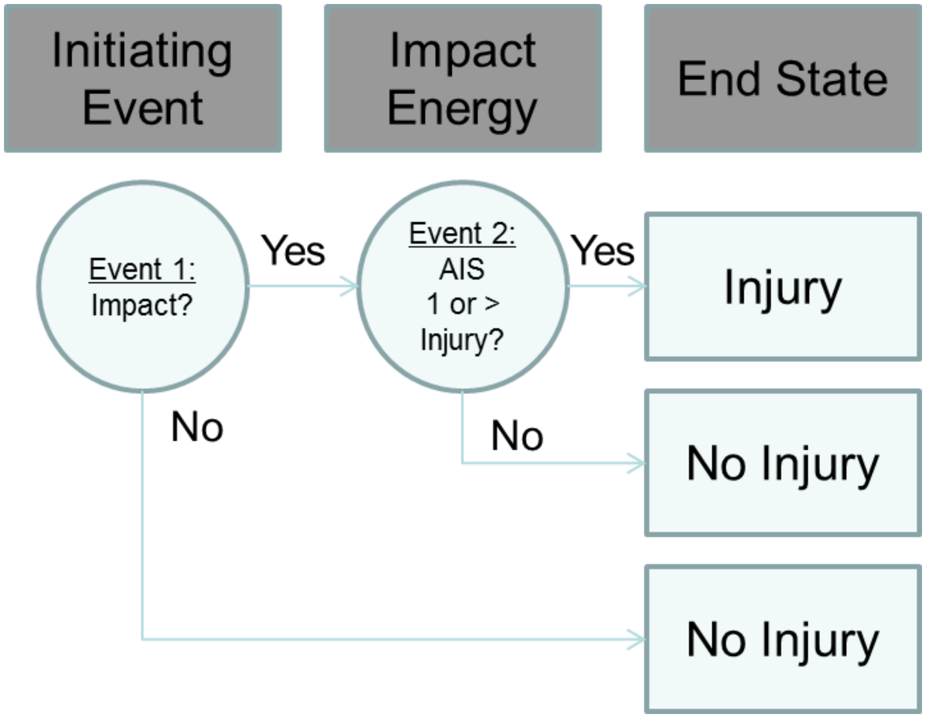
- **Discuss need for a cervical injury model to enhance current observational data for astronauts**
- **Development of a complex Biomechanical model of the spine that can accommodate specific scenario conditions unique to the space flight environment**
- **Validation and verification of model components using terrestrial information**
- **Utilization of the model to assess the likelihood of a cervical spine injury at the AIS=1 level.**
  - Qualitatively validated against observed phenomena
- **Potential future efforts**





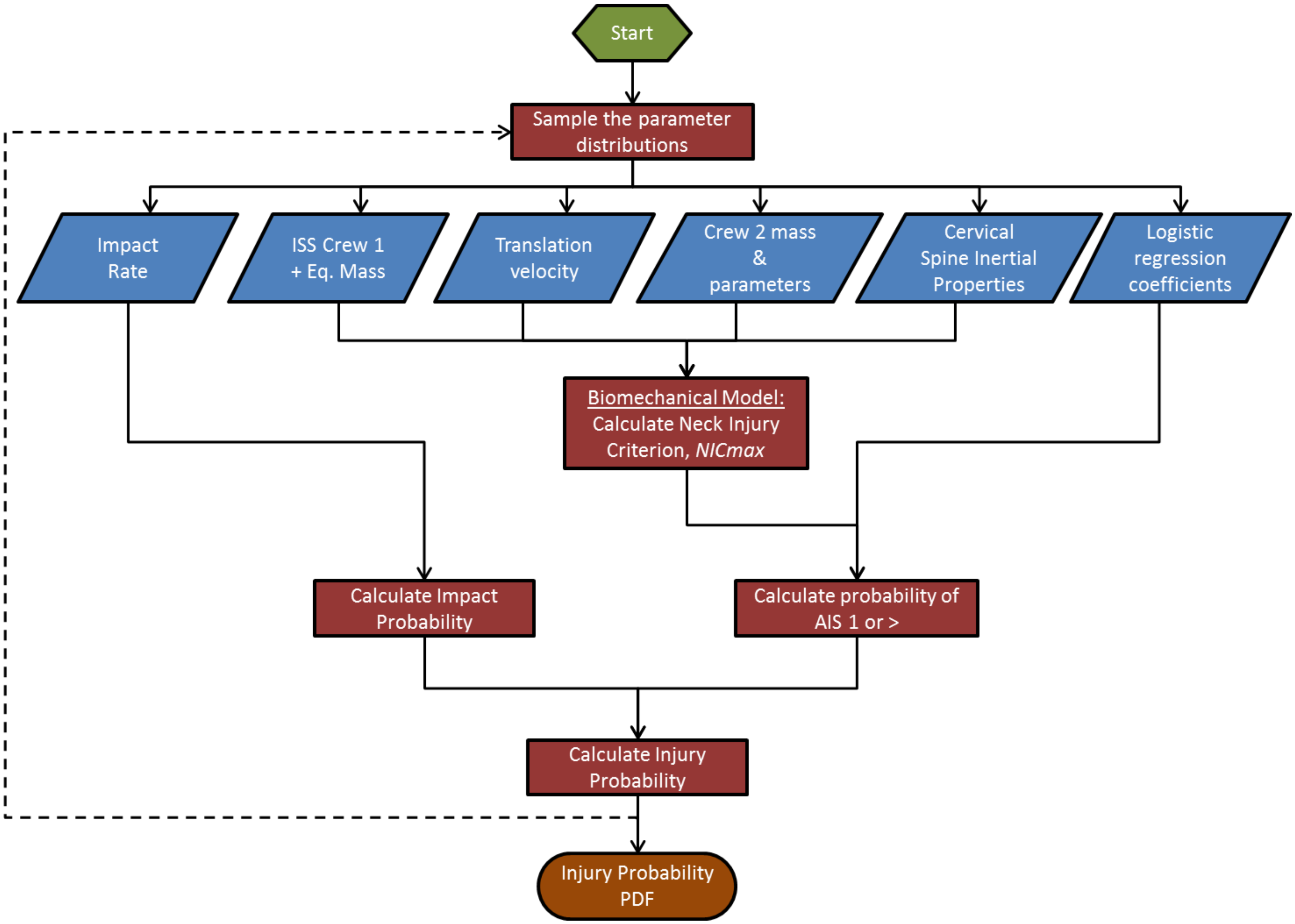


Injury Scenario

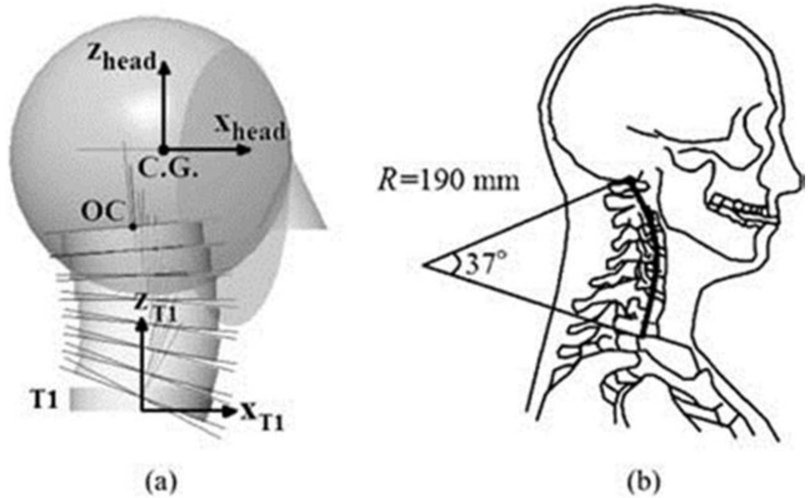


- Scenario
  - Crew 1 is moving through a primary or standard translation path transferring large volume equipment.
  - Crew 1 impacts stationary Crew 2 on the superior posterior thorax with a transient acceleration.
  - Crew 2 cervical spine is inertially loaded from the mass of the head producing an extension-flexion motion deforming the soft tissues of the neck

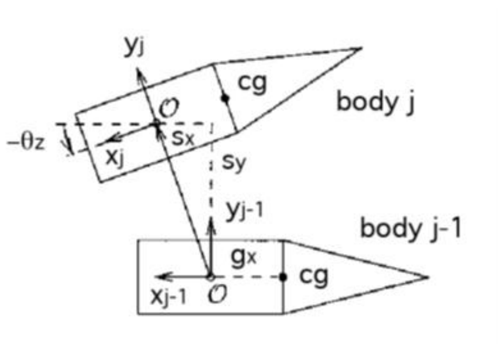
Probabilistic Modeling Scheme



Biomechanical Model of the Cervical Spine



[Himmetoglu et al., 2007]

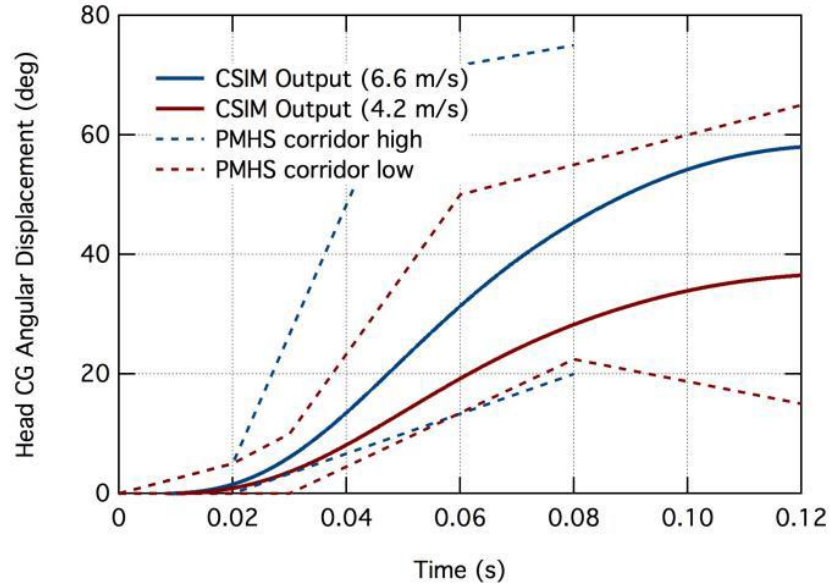


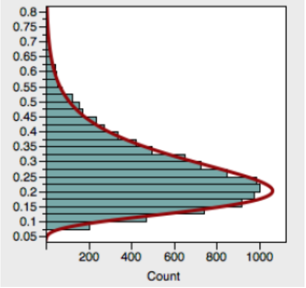
[de Jager, 1996]

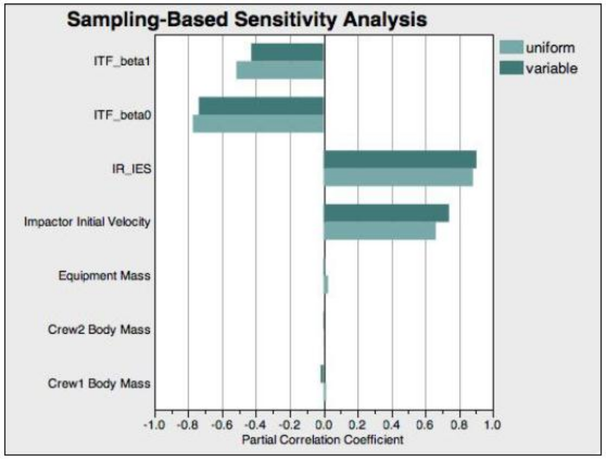
- Biomechanical model
  - Comprised of eight rigid bodies
    - Individual inertial properties
  - Connected by nonlinear viscoelastic rotational elements
    - Represents the collective behavior of an intervertebral disc, ligaments, facet joints, and muscles resist external loads
- Inertial properties of the head and neck were lumped into the rigid bodies
- Intervertebral Joint Soft Tissue Model
  - Modeled as a rotational spring in parallel with a rotational damper
- Implemented in SimMechanics

Toward Credibility Assessment of CSIM

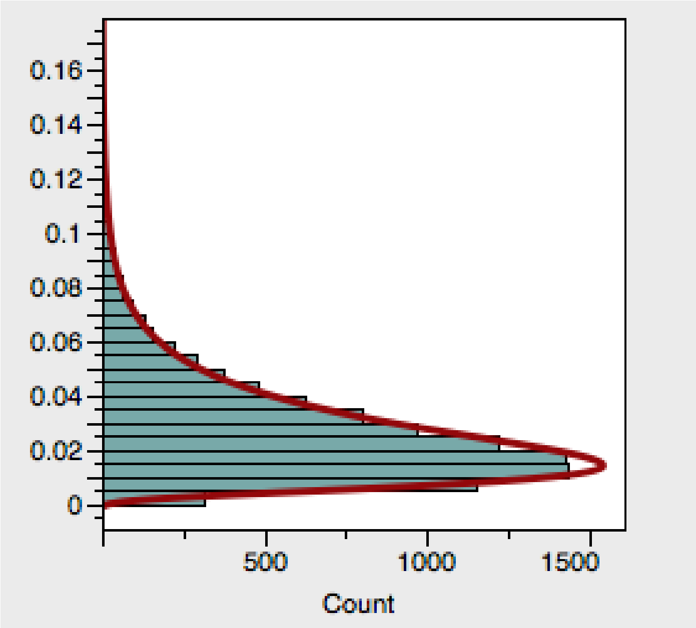
- Validation
  - Kinematic validation for head CG angular displacement
  - Two cases (high and low initial pendulum velocity) [Viano, 2001]
  - High velocity impact is within the high injury corridor
- Uncertainty
  - Evaluated 6 parameter propagation
- Sensitivity
  - Crew 1 Body Mass (X1)
  - Equipment Mass (X2)
  - Crew 2 Body Mass (X4)
  - Impact rate (for IES neck injuries), IR_IES (X7)
  - Impactor Initial Velocity (X3)
  - Logistic regression coefficients







Cervical spine injury at the AIS=1 level



Summary Statistics

Mean	0.0277211
Std Dev	0.0201244
Std Err Mean	0.0002012
Upper 95% Mean	0.0281156
Lower 95% Mean	0.0273266

- ISS 6-Month Increment
- Successfully combined the probability of an AIS1 injury with the probability of the ISS impact scenario
- Future Efforts:
  - Extend validated modeling approach to higher level AIS injuries
  - Extend to additional injury scenarios that require similar biomechanics responses.
    - Adaptable to exploration scenarios/vehicles

Questions?

Medicine is a science of uncertainty and an art of probability.

William Osler

Probabilistic Input Data

(Xk) Input Factor	Distribution	Range	Units	Remarks
(X1) Crew 1 Body Mass	Normal(81, 15)	45(5^{th} pctl M&F) 105(95^{th} pctl M&F)	kg	(M, SD); [ADS, 2006]; aleatoric
(X2) Equipment Mass	Uniform(334.3, 451.8)	334.3(min) 451.8(max)	kg	[SME]; aleatoric
(X3) Impactor Initial Velocity	Exponential(0.8819)	0.15(min) 2.0(max)	m/s	(M); [SME] ; aleatoric
(X4) Crew 2 Body Mass	Normal(81, 15)	45(5^{th} pctl M&F) 105(95^{th} pctl M&F)	kg	(M, SD); [ADS, 2006] ; aleatoric
(X5) ITF_beta0	Normal(1.668, 0.4686)	0.7892(L 95% CI) 2.639(U 95% CI)	1	(M, SE); logistic regression coefficient; aleatoric
(X6) ITF_beta1	Normal(-0.1166, 0.0362)	-0.1912(L 95% CI) -0.0485(U 95% CI)	$(s/m)^2$	(M, SE); logistic regression coefficient; aleatoric
(X7) IR_IES	Gamma(3.0, 1/26.44)	NA	NA	(shape, 1/scale); [SME] ; epistemic
M – mean SD – standard deviation SE – standard error SME – subject matter expert				